ARMY RESEARCH LABORATORY

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Abstract

A multi-year effort was conducted to investigate the impact on human cognitive and physical performance capabilities resulting from the introduction of a new Army command and control vehicle with modernized digital communications systems. This was a joint effort by the U.S. Army Research Laboratory in partnership with the Directorate of Force Developments at the U.S. Armor Center and School at Fort Knox, Kentucky, and the U.S. Army Operational Test and Evaluation Command at Alexandria, Virginia. Literature searches and background investigations were conducted, and a model architecture based on a taxonomy of human performance was developed. A computer simulation design and methodology was implemented with these taxonomic-based descriptors of human performance in the military command and control domain, using a commercially available simulation programming language. A series of computer models was written and results were developed that suggest that automation alone does not necessarily improve human performance.

CONTENTS

COHOST (COMPUTER MODELING OF HUMAN OPERATOR SYSTEM TASKS) COMPUTER SIMULATION MODELS TO INVESTIGATE HUMAN PERFORMANCE TASK AND WORKLOAD CONDITIONS IN A U.S. ARMY HEAVY MANEUVER BATTALION TACTICAL OPERATIONS CENTER

INTRODUCTION

In today's technology-based society, new machines and systems that would have been undreamed of only a few short years ago have rapidly proliferated and become a way of life. Developments and advances, especially in the areas of digital electronics and micro-circuitry, have spawned subsequent technology-based improvements in transportation, communications, entertainment, automation, and many other areas, which would not have been possible otherwise. This rapid "explosion" of new capabilities and ways of performing tasks has been partially motivated by the philosophy that if it is possible to make something better or work faster or be more cost effective or operate over greater distances, then it must be inherently good for the people who will use and benefit from the new products, services, systems, and machines produced as a result.

The formal concept of human-system interface design has only emerged this century as a recognized academic discipline; however, the practice of developing ideas and concepts for new products for which the human is the primary user and benefactor has been in existence since man started experiencing cognitive thought.

One example of a human-system interface technology for communication and dissemination of information that has evolved over centuries of trial and error development is the book. It is no accident that the form and shape of today's book of are as they are. The book's optimal configuration was determined by centuries of trial and error until it has become readily usable. This slow evolution was mirrored by a rate of technological evolution that allowed new technological advances to be experimented with as part of the overall use requirement and need for the existence of the printed word and some way to contain it.

Today, however, technology is advancing at such a rapid rate that evolutionary use requirements have no chance to develop alongside the fast-paced technological advances. One result of this recognition is the establishment of disciplines such as human factors engineering, which have stated purposes and goals of systematic determination of good and bad human-system interface designs. However, other results of this phenomenon are systems that are developed and placed into public use simply because new technology allowed them to be made.

This development can proceed without a full appreciation of how the system might be used and, perhaps even more significantly, without regard to the impact that the use of this new system might have on the person(s) using it. The U.S. Army has a term for this type of activity: "stove-piped development." The implication of this term is that a system is developed in isolation where the developers are only looking "up" and not "around" and where they are thus concerned only with how this system may work or be used for its own singular purposes and not how it might be used in the larger community of existing systems and interfaces or, even more importantly, in the larger community of other new systems in concurrent development.

Some of the impacts for the Army are communication systems that work exactly as designed but are unable to interface with other communications systems in other domains for battlefield-wide communications capabilities. Having communications systems that cannot communicate with each other is one problem, but when developments in one industry produce products that humans use or attempt to use with products from totally separate developments or industries, the Army's concept of product development resulting from stove-piped design visions can have significant implication on the use and operation of each system and the human operator attempting to use them.

Many examples would illustrate this concept; however, one that is explored here is the Army's effort to develop and field a new command and control vehicle (C2V) replete with a suite of "state-of-the-art" digital communications systems. Considering the vehicle as one human-in-the-loop system and the digital C2 systems as a second, each system is the product of a significant development process that has proceeded without any thought or consideration of the other until recently.

As is often the case, the vehicle is derived from a proven platform developed to support another program. This program is the multiple launch rocket system (MLRS) which uses vehicle technology from the Bradley armored fighting vehicle (AFV) program. The MLRS and AFV derivatives provide a vehicle platform that has good cross-country mobility and speed, considerable range, and well-developed maintainability capabilities. This vehicle, along with the M1 main battle tank, provides the basic cross-country high maneuverability rates that are required by modern land warfare doctrine. Choosing the well-developed MLRS vehicle platform was therefore logical for a C2V that needed the ability to maintain overland movement rates with the main battle forces. The digital communications systems now in development and initial fielding in order to test units comprise a revolutionary attempt to capitalize on modern technology to provide greater information throughput at extended ranges with fully integrated

dissemination to all command levels. These systems are also being developed with highly sophisticated techniques for transmission security, which include such concepts as active frequency hopping and digital burst communications. Systems that are incorporated into the family of Army battle command systems (ABCS) include the maneuver control system-Phoenix (MCS/P) for friendly unit command and control, the all-source analysis system (ASAS) for tracking enemy forces, the advanced field artillery tactical data system (AFATDS) for artillery mission processing, the combat service support control system (CSSCS), the forward area air defense (FAAD) command, control, and intelligence (C2I), the applique interim maneuver control system and the integrated meteorological system (IMETS) weather information dissemination (see Figure 1).

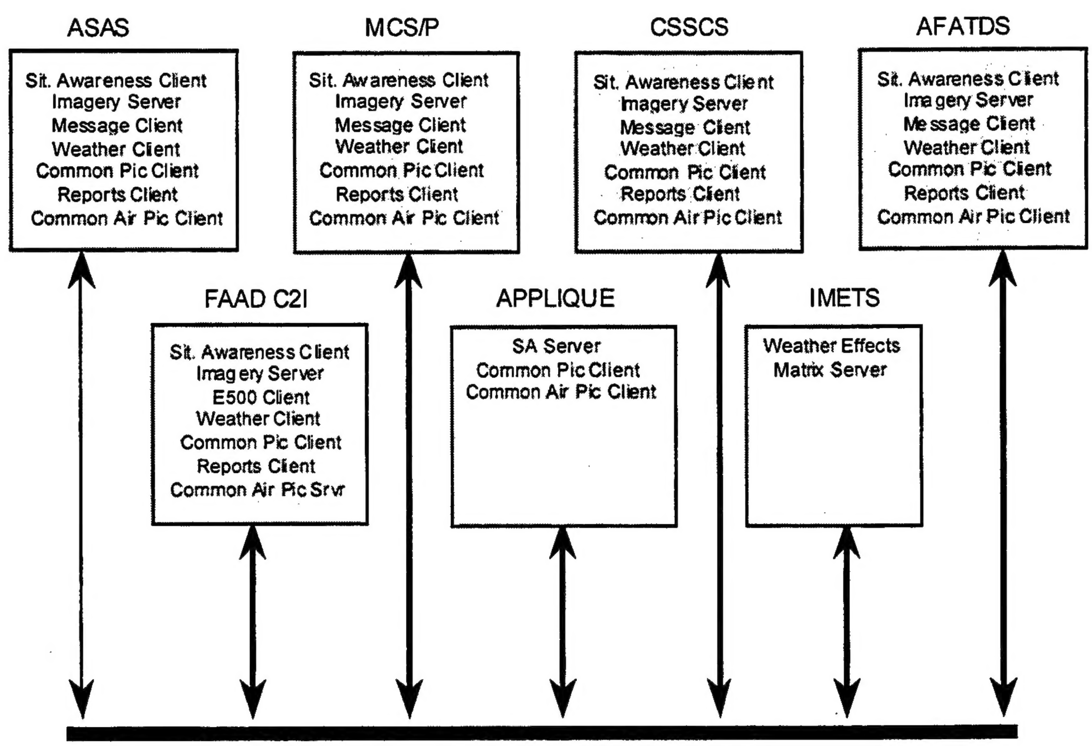


Figure 1. Army battlefield command system (ABCS) architecture client-server diagram.

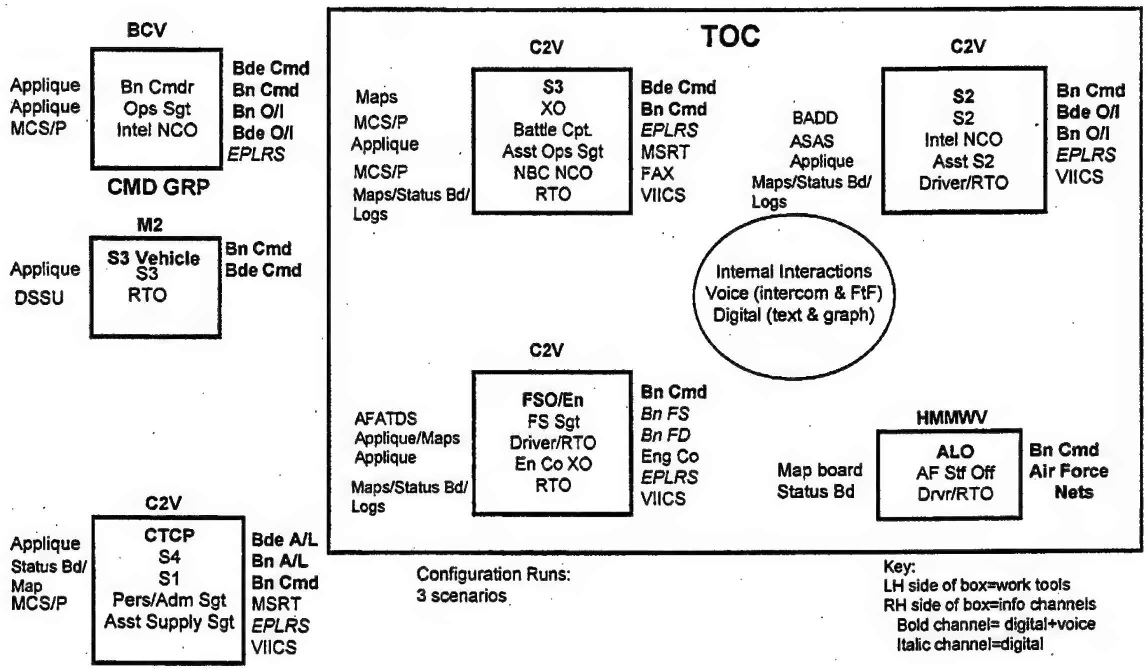
Many of these systems use common computer hardware, and the installation of system consoles into the working space of the C2V is directed toward providing a real-time command, control, and communications (C3) capability that can be performed while the vehicle is moving. The C2V itself is designed to have a two-person crew for vehicle driving and movement control in the front cab with as many as four computer workstations and two auxiliary "jump" seats in the rear working compartment. An auxiliary 40-kilowatt power generator provides power for the

computer systems and associated radio transmission equipment for operation while the vehicle is moving or stationary with the main engine off. From a hardware design viewpoint, this integration of a modern vehicle platform with state-of-the-art communications capabilities directly addresses anticipated current and future battlefield C2 requirements well into the next century. However, this vehicle and its systems are at the heart of a change in the operational paradigm in C2 tactical operations centers (TOCs) that the Army is now undergoing.

For the 50 years since World War II, the basic nature, organization, and mode of operation of command organizations have remained unchanged. Staffs are organized on a basic four-section structure, and TOCs generally only operate in a totally static mode with the amount of time required to move them to keep pace with a mobile battlefield going almost exponentially from lower to higher command levels. However, current initiatives are changing all that, and while new vehicles and hardware systems address the ability of the command structures to improve their operations, these initiatives do not necessarily provide the environment in which a human-in-the-loop operator can necessarily function in a more effective manner. This project addresses the ability of the human component of the new operational systems to perform under a new operational paradigm. While communications systems are passing greater and more accurate volumes of information in real time, can the soldier absorb and be able to react to the stream of data being presented to him or her, also in real time? Can these activities be performed while the vehicle is moving over extended distances and during extended time periods? Do the combined effects of fatigue, noise, and vibration that are sustained by an operator cause that person to become what is described as a "cognitive casualty"? The computer modeling of human operator system tasks (CoHOST) computer models address these issues and others. Some basic assumptions that have been made with the work to date are that the operator is fully trained and is qualified to perform the job assigned. It is also assumed that reaction tasks are performed when they are required. In other words, when a task is passed to an operator who requires certain actions to be performed in response to it, the operator performs those responses if he or she is able without deciding if he or she wants to do so.

The objective of this effort was to produce an integrated C2 soldier task performance and workload model for a maneuver battalion task force (shown in Figure 2), equipped with mature Force XXI ABCS digital equipment projected for use by the Army, using a computer-based application environment for modeling. The model was to be used to assess the efficiency of information flow and task loading during an extended mission and to compare soldier task and workload outcomes from this model to those from other model runs in order to answer such questions as (a) is one configuration of personnel and communications equipment better or worse

than another? or (b) can the human operator continue to function effectively during extended periods of moving operations in the vehicle?



A/L = administration/logistics
ALO = air liaison officer
BADD = battlefield automated digital display
bde = brigade
bn = battalion
cmd = command
DSSU = should be DSCS (defense satellite communications system)
EPLRS = enhanced position location reporting system
MSRT = mobile subscriber radio terminal
NBC = nuclear, biological, chemical
NCO = noncommissioned officer
RTO = radio telephone operator
VIICS = vehicle inter/intra communications system

Figure 2. Tactical operations center (TOC) diagram.

APPLICATION OF A TAXONOMY OF HUMAN PERFORMANCE

With work first published in 1954, Edwin Fleishman (1975) began what would become a lifetime of effort focused on the development of a taxonomic descriptor of work performance. The resulting taxonomy (Fleishman & Quaintance, 1984) presents a set of skills and abilities that can be used to describe human performance characteristics in any general work situation. Fleishman stated (1975, 1978) that some kind of taxonomy of human performance is required, which provides an integrative framework and common language applicable to a variety of basic and applied areas. He further stated that predictions and generalizations about human performance appear to be enhanced by some linkage of task classification systems based on human abilities and task characteristics. In 1988, Fleishman quoted 1947 work by others with the observation that apparatus tests of perceptual motor abilities had been found to have considerable validity for predicting the success of

pilots and bombardiers in completing training during World War II. Comments by others point out that Fleishman's work tends to be neglected in the mainstream of human information processing research, perhaps because the skills and abilities in the taxonomy are only based on factor analyses and are void of any process description. However, the tests used by Fleishman to develop the taxonomy belong to the same type of performance tests that are studied in Wickens' more accepted dual task experiments and therefore deserve closer scrutiny (Sanders, 1997). There have been many attempts in the human factors community to develop similar descriptions of human performance, and while this taxonomy may not be generally accepted by all for every attempt at evaluations of human performance, it does provide a set of skill and ability descriptors that are heavily weighted to cognitive performance.

Previous work at the U.S. Army Research Laboratory (ARL) (Knapp, 1996, 1997; Knapp et al., 1997a through 1997c; Schipani et al., 1998) and the U.S. Army Research Institute (ARI) (Seven, Akman, Muckler, Knapp, & Burnstein, 1991) identified a job skill and ability taxonomy (Fleishman, 1984; Fleishman & Quaintance, 1984), which showed promise to provide the basis for workload scaling in Army battalion level C2 modeling efforts. This taxonomy consists of 52 skills and abilities that include mental processing, sensory perception and fine and gross motor skills. The selection of this taxonomy was influenced by its detailed decomposition of mental abilities and the existence of behaviorally anchored rating scales (Knapp et al., 1997b). Subsequently, 50 of the 52 skills and abilities from the taxonomy were adopted to support work that was performed for the U.S. Army Intelligence Center at Fort Huachuca, Arizona. This work sought to determine basic soldier training requirements needed to provide requisite skills and abilities for various military occupational specialties (MOSs) at the Intelligence Center's basic soldier training units. As shown in Figure 3, the taxonomy was grouped into eight demand categories (reasoning, speed loaded, conceptual, communications, visual, auditory, psychomotor, and gross motor). From Knapp (1997b), "Each skill and ability has an associated behaviorally anchored rating scale that ranges from '1' for a very low level demand, to '7' for the highest demand. Definitions for all 50 skills and abilities, along with their behaviorally anchored scales, are documented in Seven et al. (1991)." The original use of the taxonomy was supported by a manual data collection instrument called the job comparison and analysis tool (JCAT) as documented by Seven. Knapp used this in 1996 to investigate skill and ability requirements for the 96B MOS for the Army and for nurses' requirements in hospital emergency rooms. As more experience was gained with the taxonomy, it was decided to automate it into a computer-based tool (Knapp & Tillman, 1998). This new tool was named the job assessment software system (JASS) and capitalizes on computer technology by implementing logic decision tree structures to determine which skill and ability would be queried to the survey respondent, based on initial task-based question responses.

Cognitive Skill and Experience Clusters

Communication
1. Oral Comprehension
2. Written Comprehension
3. Oral Expression
4. Written Expression

Conceptual (1.20)
5. Memorization
6. Problem Sensitivity
7. Originality
8. Fluency of Ideas
9. Flexibility of Closure
10. Selective Attention
11. Spatial Orientation
12. Visualization

Reasoning (1.25)
13. Inductive Reasoning
14. Category Flexibility
15. Deductive Reasoning
16. Information Ordering
17. Mathematical Reasoning
18. Number Facility

Speed-loaded (1.22)
19. Time Sharing
20. Speed of Closure
21. Perceptual Speed and Accuracy
22. Reaction Time
23. Choice Reaction Time

Cognitive skills weighted in the model

Perceptual-Motor Ability Clusters

Vision
24. Near Vision
25. Far Vision
26. Night Vision
27. Visual Color Discrimination
28. Peripheral Vision
29. Depth Perception
30. Glare Sensitivity

Audition
31. General Hearing
32. Auditory Attention
33. Sound Localization

Psychomotor
34. Control Precision
35. Rate Control
36. Wrist-Finger Speed
37. Finger Dexterity
38. Manual Dexterity
39. Arm-hand Steadiness
40. Multi-Limb Coordination

Gross Motor
41. Extent Flexibility
42. Dynamic Flexibility
43. Speed of Limb Movement
44. Gross Body Equilibrium
45. Gross Body Coordination
46. Static Strength
47. Explosive Strength
48. Dynamic Strength
49. Trunk Strength
50. Stamina

Fleishman, E. A. and Quaintance, M. K. (1984) Taxonomies of Human Performance: The Description of Human Tasks., Orlando: Academic Press.

Figure 3. Skills and abilities taxonomy.

JASS DATA COLLECTION INSTRUMENT

JASS runs on IBM-compatible PC computer systems with Pentium® processors running Microsoft Windows™ 95 or later. JASS allows multiple tasks to be queried for each skill and ability and has built-in capabilities to reduce the raw data collected from a survey pool to mean values with indicated standard deviations, thus making them ready for immediate analytical use after data collection is finished. The JASS data are stored in Microsoft Access™ database format that includes data tables containing the job assignments, questions, behaviorally anchored scales, raw scores, and reduced results. If desired, other questions can be added to the question and scales tables to collect data to either augment the skill and ability data or to gather additional information such as magnitude estimation opinion responses from the respondent for other analytical purposes.

Each question and answer sequence in JASS begins with exploratory questions that determine if that category of skills and abilities applies to the task being evaluated. Once it has been determined that the task being evaluated is applicable to the skill category being evaluated (e.g., ORAL COMPREHENSION), then questions are presented that query for a magnitude of application responses from the survey respondent. Figure 4 shows a data collection screen from

JASS, which results from using the computer mouse to click on the "yes" response to the exploratory question. These data collection screens are all supported by individual anchors for each question that solicits data for each skill and ability of the taxonomy.

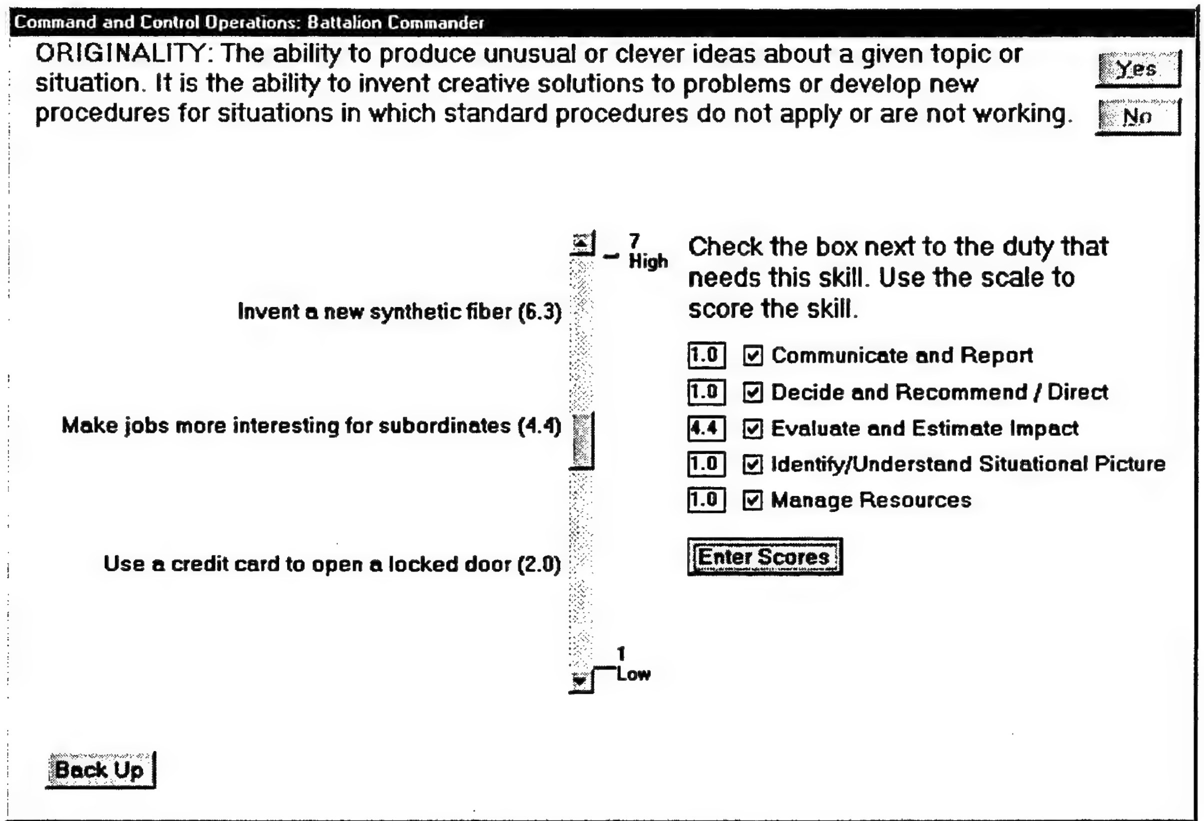


Figure 4. JASS data collection screen.

The survey respondent enters data by first clicking on the check box next to the question with the computer mouse and then using the mouse to move the vertical slider on the scale labeled from 1 (low) to 7 (high) to indicate the desired choice of 1 to 7. As the slider moves up and down on the anchor scale, the number in the box to the left of the check box automatically registers a number of 1 to 7, depending on how far up the scale the slider is moved. The anchors are proportionally placed on the scale. In the Figure 4 example, the middle "Make jobs more interesting…" anchor represents a scale value example of 4.4. Work by Knapp, Seven, Tillman, and others, working from Fleishman's original documentation, validated the anchors and anchor placement on the 7-point scale in the performance of earlier projects.

As shown in Figure 4, the JASS database configured to support the current CoHOST computer model studies has five task-oriented questions related to performance of battle space

management and C2-related activities in a battalion TOC during combat activities. These tasks were identified early in the project as a result of extensive interviews with active duty U.S. Army officers, noncommissioned officers (NCOs), and enlisted personnel acting as subject matter experts (SMEs), who had experience working in battalion TOCs. The five job tasks are

1. Communicate and report,
2. Decide and recommend or direct,
3. Evaluate and estimate impact,
4. Identify or understand situational picture, and
5. Manage resources.

A demographic questionnaire preceding the JASS survey determined the operator's background and level of experience in such duty positions as Battalion Commander, Battle Captain, S3 NCO in charge (NCOIC), Air Liaison Officer, and radio telephone operators. Twenty-four duty positions were selected to be included in the C2 work team, of the approximate 900 individuals in a battalion headquarters unit. These 24 were selected because they take an active role in the group of people who are actually engaged in battle space management and decision-oriented C2 activities during combat operations. Under this criterion, such individuals as the Battalion Sergeant Major, the highest ranking noncommissioned officer (NCO) in the battalion, were excluded because his duties are rated as being combat service support in nature during tactical operations that organize support activities behind the scenes. Other individuals, such as some of the lowest ranking privates and corporals in the battalion, were included because their duties involve radio operator communication for various sections, passing and receiving combat communications traffic. A complete list of the operators included in the current CoHOST models is shown in Table 1.

SCENARIO

The battalion task force mission was modeled as a force-on-force operation occurring over several hours. Different scenarios that have been developed include the phases of pre-operations planning, movement to contact, deliberate defense, and hasty attack. Some scenarios reflect heavy combat actions and others reflect extended movement and reconnaissance type operations. A model input file consisting of scenario voice and digital messages expected to be sent to and from the battalion during the course of the tactical mission was generated using battalion-training scenarios for southwest Asia (SWA) operations and operations mission summary-mission profile (OMS/MP) movement rates as provided by the U.S. Army Armor Center (USAARMC). The input file indicates the time each message occurs, where it is received, who or what equipment

receives it, and the subsequent routing and task flow initiated by this message. Tasks performed in response to these messages come from an external source (usually a radio, digital link, or coworker) and are labeled "reactive," and either "voice" or "digital." In addition to external messages, the scenario file also contains "internal information messages" that are mental "triggers" for personnel to periodically perform "proactive" (self-initiated) tasks that are an essential part of C2 operations and workstation database manipulation. Examples of these proactive tasks are situation assessment checks, updating documentation (plans, orders, etc.), preparing status reports, and requesting windows of information for review. A sample listing from this is shown in Table 2.

Table 1

Duty Positions Modeled in the Heavy Maneuver Battalion CoHOST Models

Number	Model code number and name	Operator
1	1-SINCO	S1 section NCO
2	2-S1	S1 officer
3	4-S2RTO	S2 section radio telephone operator
4	5-S2NCO	S2 section NCO
5	6-S2O	S2 officer
6	7-S2A	Assistant S2 officer
7	9-S3RTO	S3 section radio telephone operator
8	10-NBCNCO	NBC section NCO
9	11-S3NCO	S3 section NCO
10	12-BC	Battle captain
11	13-XO	Battalion executive officer
12	15-S4NCO	S4 section NCO
13	16-S4	S4 officer
14	18-ALO	Air liaison officer
15	20-FSRTO	FS section radio telephone operator
16	21-FSO	Fire support officer
17	24-ENRTO	Engineer section radio telephone operator
18	25-ENO	Engineer officer
19	27-Loader	Battalion commander's vehicle loader
20	28-Gunner	Battalion commander's vehicle gunner
21	29-CMD	Battalion commander
22	31-Loader	S3 vehicle's loader
23	32-Gunner	S3 vehicle's gunner
24	33-S3V	Battalion S3

Table 2

Sample Scenario Message Traffic

TAG	Task type	Start	System	Message type	Receive	Income NET	TO	FROM	Message
out			A/M	A. Free			Bn SIGSO	Bde SIGSO	All Bn units to enter bde comms net (CMD, O&I, A&L, & FS)
out			A/M	A. Free			Bde Cdr	TF Cdr	request early deployment of scouts
1	R	86,87	A/M		A. Free		TF Cdr	Bde Cdr	early scout deployment request granted
2			A/M		A. FRAGO		S-3V	TF Cdr	deploy scouts
out			A/M	A. FRAGO			all units	S-3V	deploy scouts
3	R	33,32	V & A/M		C. Position	o/i	S-2	scouts	sierra papa
4		22	all		C. Free		S-2	Bde S-2	all source intel weather, intel rpts
			A/M		C. Free		CDR intel	S-2	all source intel weather, intel rpts
800	P		A/M	Non-task		cmd		TF Cdr	CDR check status of battlefield
out			A/M	B. REDCOM of A. Free		cmd	all units	S-3	REDCON report
5	R	32,33	A/M		B. REDCOM	cmd	S-3	a1-10	Apache 06, REDCON 1
6	R	32,33	A/M		B. REDCOM	cmd	S-3	d1-10	Bounty Hunter 06, REDCON 1
7	R	32,33	A/M		B. REDCOM	cmd	S-3	c1-91	Desperato 06, REDCON 1
8	R	20,22	V & A/M		C. Position	o/i	S-2	scouts	crossing QT/QU grid line
9	R	32,33	A/M		B. REDCOM	cmd	S-3	a23d eng	Sapper 06, REDCON 1 - bat 1 ea CEE blew hydros need BMO
10	R	32,33	A/M		B. REDCOM	cmd	S-3	2/a 1-440 ADA	Goosewhite 06, REDCON 1

ADA = air defense artillery
A/M = Applique and MCS
BMO = battalion maintenance officer
Cdr = commander
CEE = combat engineer excavator
FRAGO = fragmentation order
FS = fire support
LD = line of departure

O/I = operations and intelligence
P = proactive
R = reactive
REDCON = readiness condition
SIGSO = signals officer
TF = task force
V & A/M = voice and applique/MCS

COMPUTER MODEL

Computer modelers used the commercially available simulation software program MicroSaint™, which provided software protocols and conventions, to input the tasks, task sequences, flow logic, and task timing and workload data from the network diagrams into an executable model. The computer model works according to a basic "input-throughput-output" scheme. That is, the input to the model are message events from the scenario input file, which present an information event stream in a time sequence synchronized to mission activity phases. As these information events enter the model, tasks are triggered and performed in a pattern that reflects the *a priori* logic for task branching, interrupt priorities, time outs, and collaborative (interactive) tasks. Any information event that triggers a staff huddle always has the highest priority.

The model runs on an IBM-compatible PC running Windows™ 95 (or higher). During model execution, a graphical user interface (GUI) screen displays the progress of tasks being performed by each C2 section and individual soldier position, as information messages enter the system. Bar and pie charts on the GUI display allow an observer to initially look at whether staff sections and individuals are keeping pace or falling behind in their information processing, as well as how busy or idle they are as scenario time continues. A screen print from this real-time display is shown in Figure 5.

DISCUSSION

The objective of this effort was to model C2 soldier task performance and workload in a maneuver battalion task force using a computer-based application environment for modeling. The model was to be used to assess the efficiency of information flow, task loading, and on-the-move (OTM) operations during various tactical scenarios. In addition, the model could be rerun after changes in the original soldier-equipment settings were made, to allow comparative "what if" analyses.

The model was developed in three steps that occurred iteratively and in parallel:

1. Cognitive task analysis and workload measurement for battalion C2 tasks, using techniques from the most recent human performance and related literature;

2. Obtaining and translating scenarios and task flow data from pertinent documentation and battalion C2 SMEs; and

3. Exercising a computer-based task and network modeling tool (MicroSaint™) to simulate the task and flow data from Steps 1 and 2. Following data input, the C2 computer model was debugged and executed, and the resulting output data were analyzed using descriptive and comparative statistics.

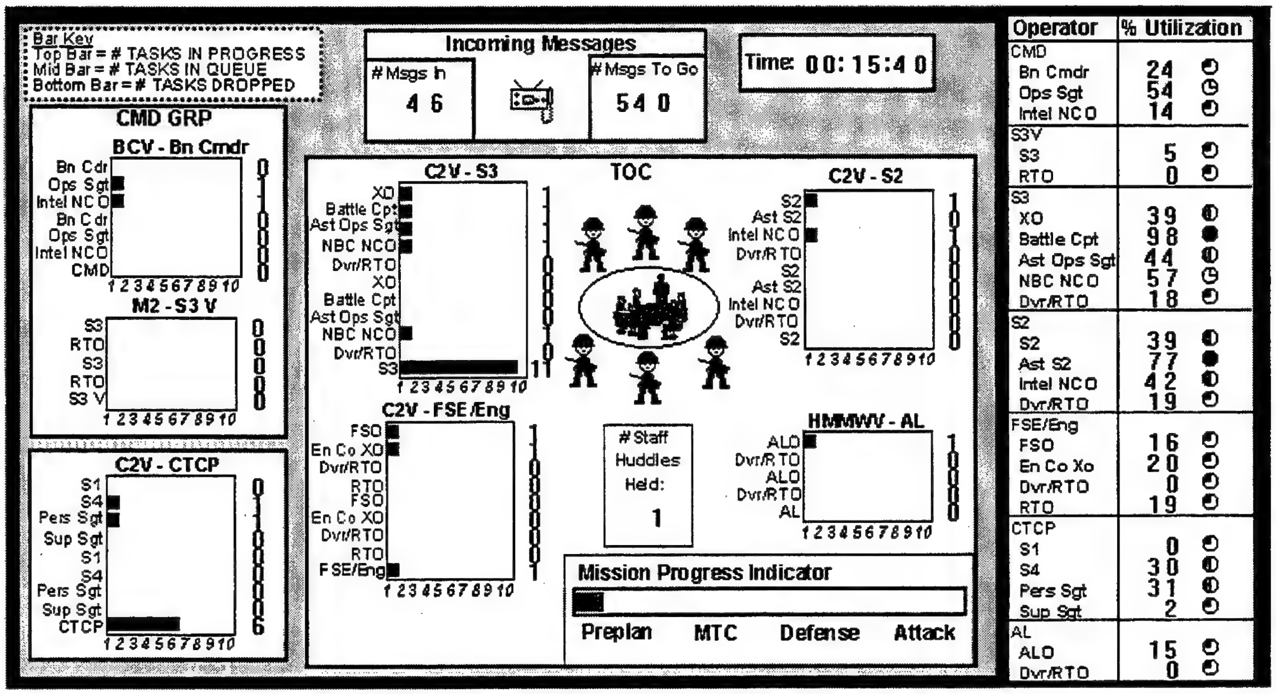


Figure 5. CoHOST model action view display.

In the design of the C2 task and workload analysis and information network flow design, cognitive psychologists and information systems engineers obtained and reviewed extensive C2 task lists and U.S. Army field manuals supplied by USAARMC and other sources. These were the starting point for modeling battalion C2 operations from the soldier performance perspective and were transformed into dynamic "task-flow sequences," or model network designs (see Figure 6). Then, the mental and psychomotor skills and abilities associated with each task were identified and measured by a task-workload scaling and scoring process.

The 50 skills and abilities in Fleishman's taxonomy range from mental processing to sensory perception to fine and gross motor skills. The detailed decomposition of the mental abilities and the behaviorally anchored rating scales associated with the skills and abilities were the primary factors impacting the selection of this taxonomy. As shown in Figure 3, the taxonomy skills and abilities are grouped into eight demand categories. Definitions for all 50 skills and abilities, along with their behaviorally anchored scales, are documented in Seven et al.

(1991). The taxonomy was used to score the individual tasks by identifying all the skills and abilities required to perform that task, and then assigning a scale value from 1 to 7 for each identified skill to reflect the demand level. For example, a task such as "look at status board" has visual, conceptual, and reasoning requirements that include near vision, perceptual speed, and mathematical reasoning. The total of these scale values is the *a priori* task workload.

Detail Job Function
(To Be Used In The Model)
1-Receive and Record
2-Handover (Inside the Section)
3-Listen / Monitor
4-Secondary Monitor
5-Log Message
6-Route (Outside the Section)
7-Send Message
8-Verbal Order
9-Roll Up Reports & Send to Brigade
10-Call to Conference
11-Decide Action
12-Decide
13-Recommend Action
14-Estimate Impact
15-Data Gathering
16-Find Options
17-Compare Alternatives
18-Discuss
19-Read
20-Scan And Decide
21-Update
22-Check Status
23-Problem Definition
24-Listen / Monitor
25-Manage Resources

Figure 6. List of tasks modeled in CoHOST computer simulations.

This initial workload value is then adjusted by three additional factors to account for the nature of and the context in which the task is being performed. First, if the task requires primarily mental processes (reasoning, speed loaded, conceptual) rather than physical processes

(vision, audition, fine and gross motor), mental tasks are adjusted to a higher score. Mental processes are given this additional multiplier (see Step 2), since proficiency in these processes requires more deliberate and complex neural transactions than the more automatic, reflexive sensory-motor tasks (see, for example, Card, Moran, & Newell, 1983).

Second, a workload score is further increased, depending on the nature of the mental processes being performed. From work conducted to model the analytical problem-solving processes of intelligence analysis, four problem-solving categories ranging from simple to complex (constructive, diagnostic, reactive, explanatory) have been identified (Burnstein, 1991). The task networks for the C2 battalion model have been coded to reflect membership in one of these categories (as shown); constructive processes present less mental demand than diagnostic, and so forth.

The final adjustment of a task workload score incorporates the effects of task duration. Each task is time weighted so that shorter tasks with higher workload are equated to longer tasks with lower workload, by averaging workload over time intervals, before summing all task values to obtain the cumulative workload for any soldier position.

The following steps are used to calculate workload for the operators while duties are performed in the TOC during combat activities:

Step 1. Score each C2 task for *a priori* workload by selecting skills and abilities from the taxonomy and determining the scale value (1 through 7) demanded to perform the task. Sum these values.

Step 2. Adjust the first workload score by the multipliers shown below; if skill-ability codes in the task are

5 through 12: multiply demand value * 1.20
13 through 18: multiply demand value * 1.25
19 through 23: multiply demand value * 1.22

Step 3. Further adjust new demand value by its task-network weight; if skill-ability codes are 1 through 33, refer to network weights in Table 3.

Step 4. Sum values for tasks to obtain final adjusted workload score.

Step 5. Take snapshots of task workload at time intervals of every 100 seconds. Divide workload scores by task duration for the interval.

Table 3

Network Weights

Network levels	Weight	Net types	Staff huddle nets
1. Constructive net	0.0	Receive and record msgs Hand over and receive Log message Listen, monitor	Call to conference Data gathering
2. Diagnostic nets	1.3	Scan boards, maps, lists Interpret and compute	Problem definition
3. Reactive nets	1.5	Decide actions - minor Route messages Issue orders and directives	Plans and orders Recommend
4. Inferencing and decision-making nets	1.8	Estimate impacts Formulate plans, directives Decide actions - major	Find options Compare alternatives Decide

These final task flow sequences or "networks" were portrayed as schematic diagrams that showed the interconnections between networks and tasks for all soldiers, from task inception to task completion. Annotations to the network diagrams were made to show the task times, task workload values, and skill-ability requirements, and task branching rules for how tasks would proceed fully or be interrupted according to predefined priorities and updates of the information environment. See Figure 7 for a sample network diagram as displayed in the MicroSaint™ programming language.

To determine battalion C2 operational task sequences and scenarios, analysts also conducted a series of structured interview sessions with a representative group of Battalion C2 military experts selected by USAARMC. These sessions were designed to systematically elicit successively more detailed and valid data detailing the C2 personnel, activities, equipment, and information interchanges that characterize combat-oriented tactical activities and missions. From these data, the networks developed previously were elaborated and verified using experts at the

National Training Center (NTC). SMEs also provided the detailed scenario voice message lists that would occur in all the different communications systems and channels entering and leaving a battalion TOC during this type of operation.

In structuring an analysis approach for data from a model run, the results were analyzed to address C2 *organizational design* and *C2 function allocation.* The organizational design analysis was to determine how the current battalion command and staff structure impacts C2 information flow and soldier workload. Organization design is defined here as the line and block C2 structure (staff sections and soldier positions), the work tools (boards, maps, logs, etc.) and the communication channels (digital and voice nets) that comprise the battalion command group and TOC. Analysis by functions was conducted to determine whether the current allocation of C2 functions and tasks (currently allocated by Army branch areas and soldier grade levels) impact C2 information flow and workload.

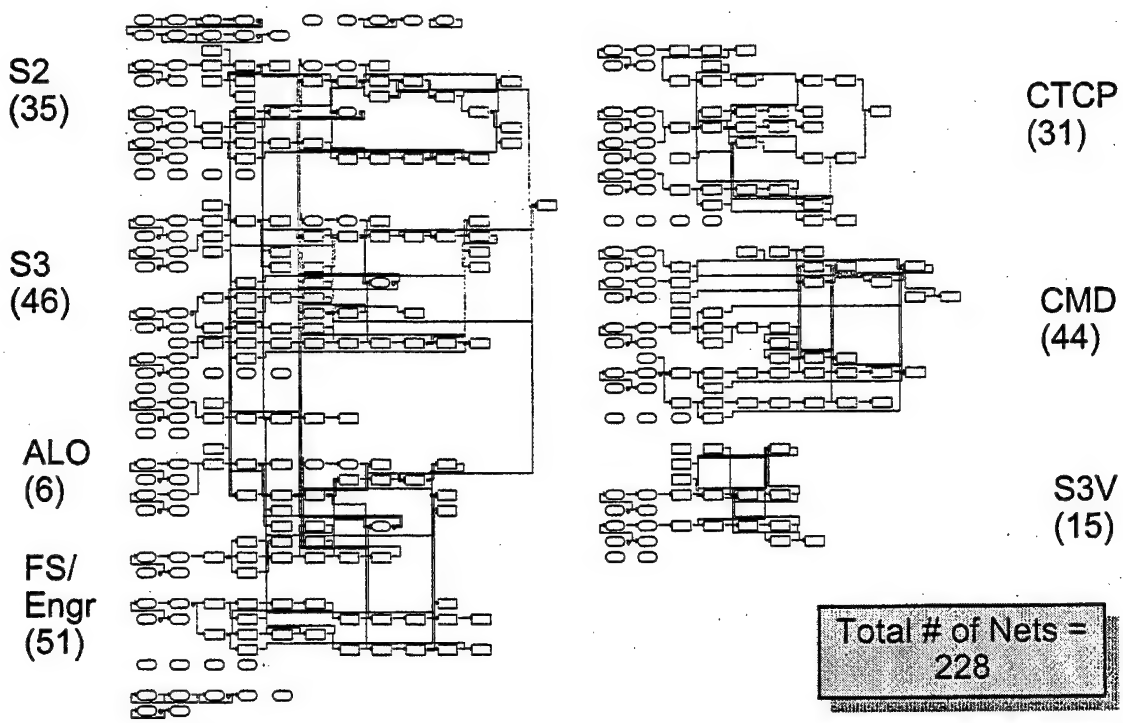


Figure 7. Sample MicroSaint™ network flow diagram.

A model "run" results in a table of model run statistics and a number of numerical data files. The model run table shows descriptive data about input to the model (information events

input, C2 nodes and personnel, etc.) and output from the model for the battalion as a whole (e.g., total running time, task networks triggered, task networks dropped, task queues generated, task backlog incurred, etc.).

Numerical data files obtained from model runs were analyzed to identify and compare information flow indicators and soldier workload indicators for staff sections, positions, and function allocation categories. Information flow was measured using

1. Tasks "dropped" - the number of task networks triggered but never completed, and the reason for their being dropped.

2. Task interruptions - the number of times and the reasons why tasks were interrupted.

3. Task queues - the number and types of task queues initiated.

4. Task "backlog" - the number and completion time for tasks still in queues, after the final information message was input to the model.

Table 4 shows reasons for task queuing, interruptions, and being dropped.

Soldier workload was measured using five indicators:

1. Utilization - the percent of time a soldier was used during the scenario.

2. Utilization profile - the distribution of task "hits": the number of times on task versus idle during each 100-second interval throughout the scenario.

3. Total workload - the cumulative workload value at the end of the scenario.

4. Workload category values - the percent of total workload value attributed to each of eight task skill-ability categories: reasoning, speed loaded, conceptual, communication, visual, auditory, psychomotor, gross motor.

5. Workload profile - the distribution of average workload level "hits": the number of high, moderate, low, and no workload during each 100-second interval throughout the scenario.

Finally, a multivariate analysis of the workload indicators was performed to determine their interrelationships in order to see the impact of workload factors on the information flow performance.

Table 4

Task Queues, Types of Interruptions, and the Reasons for Tasks Being Dropped

Types of queues	Types of interruptions
Message in S1 radio queue	Send message
Message in S4 radio queue	Receive message
Scan queue for S1	Staff huddle
Update boards queue - S1	Give orders
Message in S2 radio queue	Relay message
Log queue for S2 RTO	Gunner call sign
Read queue - S2 NCOIC	
Update boards queue - S2 NCOIC	Reasons why tasks were dropped
Read queue - S2	
Message in S3-Bde radio	In queue too long
Queue	In process too long
Log queue for S3 RTO-Bde	Interrupted by two other messages
Read queue -S3 NCOIC	
Update boards queue-S3 NCOIC	Commander or S3V unable to check status
Read queue-BC	Message in automated system more than 1,200 seconds
Message in S3-TF radio queue	
Message in FS radio queue	
Log queue for FS RTO	
Read queue - FSO	
Update boards queue-FSO	
Message in ENG radio queue	
Log queue for ENG RTO	
Read queue-ENO	
Update boards queue-ENO	
Check status queue-msg for Cmdr	
Check status queue-msg for S3V	
Update boards queue-S4	
S1 roll-up approval	
S4 roll-up approval	
Decide action queue	
ALO proactive trigger queue	
XO proactive trigger queue	

RESULTS

The battalion C2 model was executed against different scenarios using an information events list that contained voice and digital messages and internal information event "triggers" (such as a periodic reminder to check situation status), both of which initiated performance of the task networks.

In the computer models, the maneuver task force battalion C2 sections, organized into seven command and staff nodes, executed tasks according to the combat activities in the scenario. The scenario and message events list triggered tasks for all the soldier positions as they were engaged in the performance of their duties during the battle space management functions of the TOC.

To determine information flow indicators, data for each C2 section and position were compared using four measures:

1. Tasks dropped,
2. Tasks interrupted,
3. Number of task queues generated, and
4. Time required to eliminate task backlog.

These data were analyzed using a statistical procedure suited to compare significance of obtained differences among sections and positions (analysis of variance [ANOVA]).

In addition to the primary analysis, information flow was also assessed by reviewing the frequency tables, showing reasons for and types of flow bottlenecks. The results of this analysis show why tasks were dropped, what types of interruptions occurred, and what types of queues were generated during the scenario.

To determine indications of soldier workload, task load data for each C2 section and position were compared using five measures:

1. The percent of time the soldier was busy during the scenario;

2. The number of times the soldier was working tasks during each successive 100-second interval of the scenario (tasks "hits" each interval);

3. Total workload value;

4. Average workload value; and

5. The percent of task work attributable to each of the eight workload skill-ability categories.

The eight categories and their corresponding skills and abilities for three successive model runs for operators grouped by military rank are shown in Figure 8. Skill-ability category values were examined in further detail by consulting the data for each of the 50 underlying skills and abilities. This process was used to determine why a particular aggregate value for a given soldier was very high.

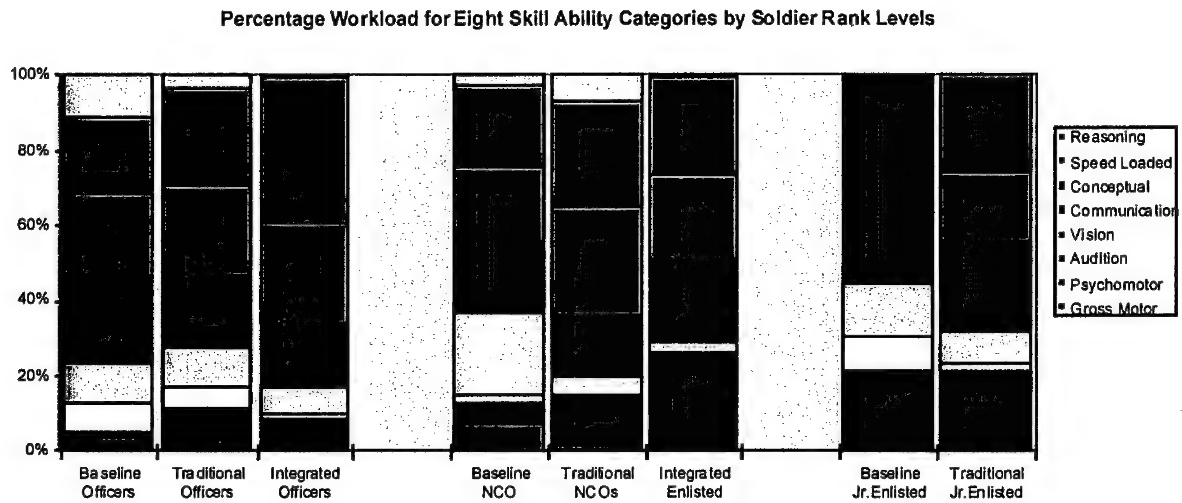


Figure 8. The percent of time spent in each performance category of the taxonomy.

Average workload values were sampled at 100-second intervals in order to show how much the work varies throughout the scenario.

Since the functions performed by soldiers in each staff section were distributed similarly according to rank and experience level, regardless of section, the functions performed by the officers are distinct from those performed by junior enlisted soldiers. These networks involve information monitoring, staff huddles and analysis, and decision-making tasks. By contrast, the enlisted tasks are devoted to information input and output processes, such as voice radio operations and message logging. The S2 and S3 sections were the only ones with an NCO. In these cases, the NCO assumed more of the officer duties than he did the input-output processes. The ANOVA results were computed by comparing information flow indicators for enlisted soldiers versus officers.

An additional analysis was conducted using multivariate statistical techniques to uncover relationships between workload measures and information flow measures. The procedure selected was hierarchical cluster analysis (hierarchical cluster scheme [HCS]). Cluster analysis statistics are used to explore relationships in data where the measures may vary in relation to one another, regardless of whether the measures currently form a distribution of absolute desired or undesired standard values. That is, can certain "clusters" of soldier positions be identified according to their relative levels on each of the workload indicators, i.e., utilization percent, selected skill-ability values, and task "hits," etc. The HCS statistic was applied to these data to compute "distance-metric" values for each soldier position and then show the relative distances from one soldier to another in a diagram. A sample HCS tree diagram (see Figure 9) shows the progressive clustering of soldier positions from many separate small clusters, until ultimately, the clustering algorithm aggregates all positions into one cluster. Major distances that occur during each aggregation step indicate the presence of discrete clusters.

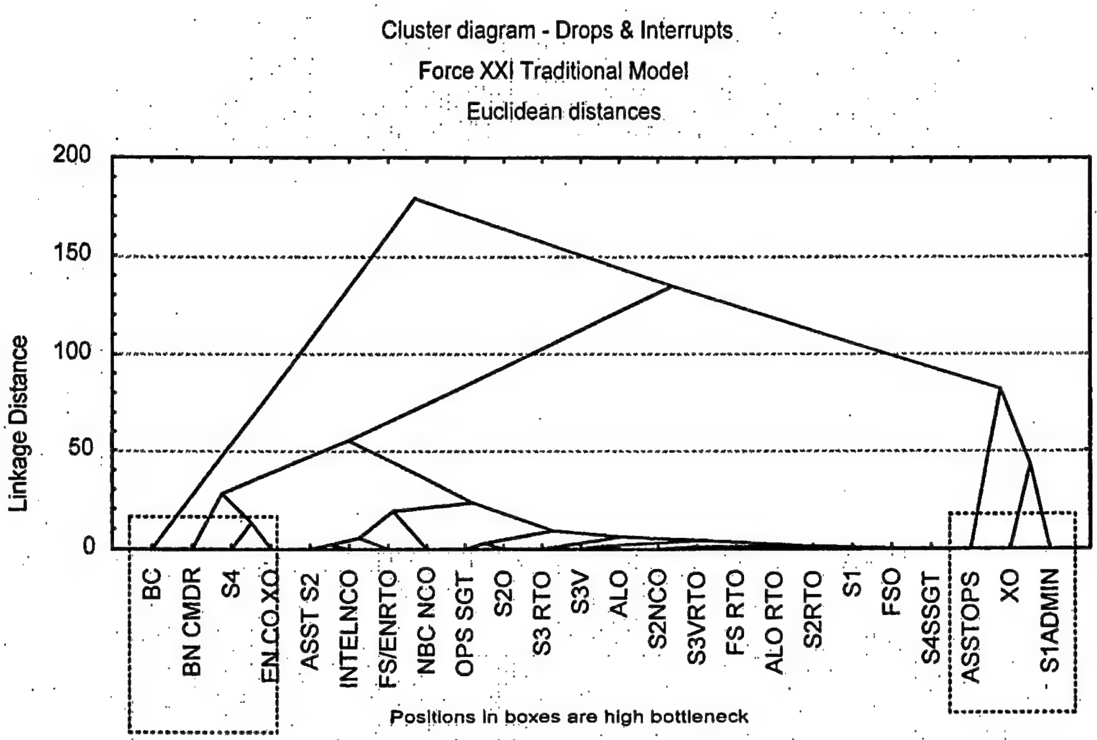


Figure 9. Sample hierarchical cluster scheme diagram.

In addition, a multidimensional scaling (MDS) analysis of workload measures showed three clusters with 20 soldiers in proximity, accounting for all but four soldiers (NBC NCO, ASST OPS SGT, XO, BC) in these clusters. The two-dimensional scatter plot for this analysis

is shown in Figure 10. Identified dimensions for this analysis are task-skill demand intensity and total task hits during the scenario. The hierarchical cluster analysis tree diagram shown in Figure 9 shows essentially the same solution obtained with the Euclidean distance metric as in the MDS. Again, the same four soldiers are only included in three more densely clustered groups if the linkage distance is increased by two or three orders of magnitude. These two distance-scaling metrics show good convergence on the number of clusters and membership inclusion criteria for soldiers in each cluster. This provides very high confidence in the interpretation.

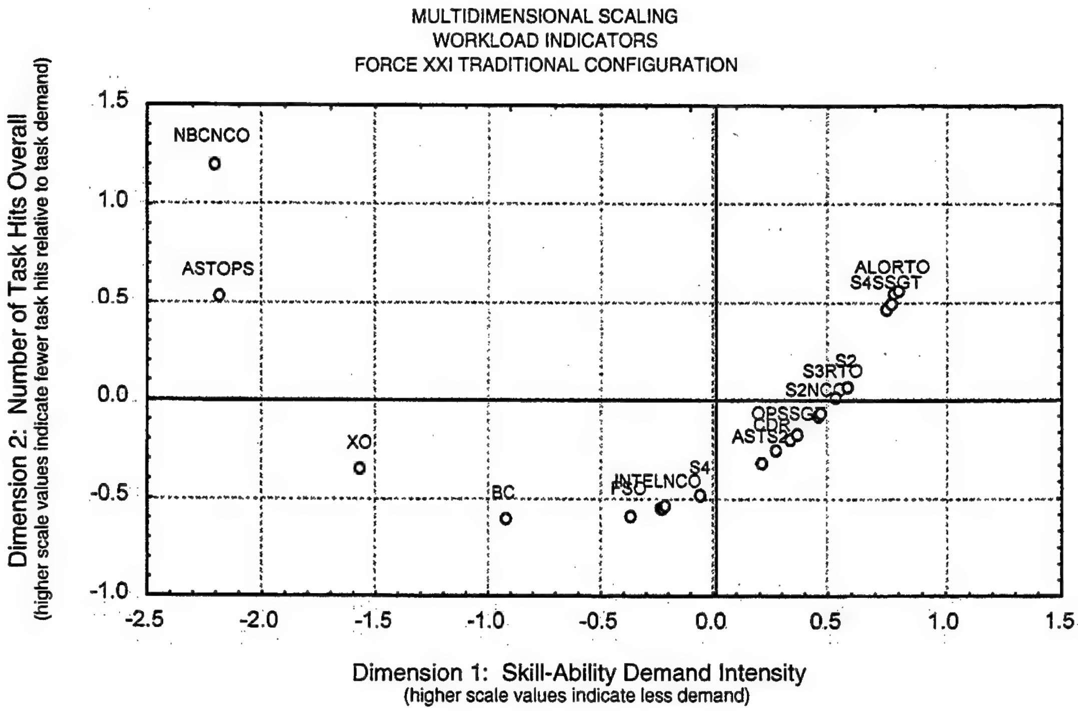


Figure 10. Multidimensional scaling plot of workload measures.

The data presented next are from one of the computer runs performed with the CoHOST models to serve as an example of the analytical procedure used to review the data and determine conclusions. This is a 2-hour scenario segment where the battalion is in a movement-to-contact tactical phase of an overall larger mission. The data show that the four task flow measures (tasks dropped, task interruptions, task queue use, and task backlog) represent different but related views of the efficiency of C2 information flow in the maneuver battalion. A statistical analysis showed no significant differences among seven staff sections using these measures. However, analysis by functions performed by different rank levels and expertise showed a significant difference in dropped tasks. Officers dropped significantly more tasks than did their support staff, regardless of whether the section had one or two enlisted soldiers. Even though the

analysis of C2 information flow indicators did not produce statistically significant results, it is clear that information flow differences are accounted for more by function than by organizational membership. Tasks were dropped for four reasons. The predominant reason was that time expired before the tasks could begin processing (e.g., 88 time-outs in a total of 106 tasks dropped). This means that a task "hand-off" could not be accepted because of an already existing soldier overload. In one model run, most tasks were dropped by the fire support officer (FSO), S3, and S2, respectively. A similar pattern is evident in the task interruption data. The S2, S3, and FSO were interrupted two to three times more frequently than any other position. From the analysis, it was determined that the overwhelming reason for interruption was to attend to new data and read them (34 interruptions of a total of 55 tasks).

Many tasks were placed into queues for completion later. The S3, S2, and FSO sections, respectively, accounted for 80% of the queues activated and used. Queues that were very frequently used were "read new information" and "update situation boards." These were primarily the functions of the S2 and S3 NCOs; in the other sections where there were no NCOs, the section officers generated more queues. Similarly, task backlogs were most pronounced for the entire S2 section, the entire S3 section, the FSO, and the engineer. Other sections generated no backlog or a backlog of less than 10 minutes. The S2 section in particular still had radio messages to be processed by the radio telephone operator (RTO) (receiving and logging) after the final external scenario message had been input.

More than half of the soldiers had a very high cumulative workload value (ranging from one to as high as 6,000) as a result of work performed during the scenario. The final workload value is a composite of many factors, including individual skill-ability demands, predominance of mental tasks, and time on tasks. Since the workload modeling is a research as well as an applied effort, no norms have yet been established for these values. However, the relative distances from one level to another, as well as the skill-ability profile associated with these tasks, allows an in-depth analysis to be conducted, which can identify specific reasons for position overload.

An important aspect of soldier workload was to what degree soldiers were used throughout the 2-hour scenario. Average utilization data points show how busy soldiers were by taking task work samples every 100 seconds. Some positions exceed levels of 75% on task for extended periods of time, such as FSO, S3, and S2. The FSO is occupied nearly 90% of the time. NCOs and other staff section officers are busy at a level of 50% to 75%. Most enlisted positions are used less than a quarter of their time overall, with the exception of the RTOs for FS, S2, and S3.

The workload data are best understood using the cluster analysis technique. A soldier who is both too busy and working at a mostly high mental demand is a bottleneck to situation awareness and timely assessment of the impact of new battle developments. There are several groups of personnel who cluster together according to these multiple indicators and who in turn are responsible for impeding information flow. Reviewing the HCS diagram reveals these clusters:

Condition Blue: S4 RTO, air defense artillery (ADA) RTO, XO, S3 RTO Bde

Condition Green: S2 RTO, FS RTO, S3 NCO, loader-commander (LDR-C), LDR-S, S3 RTO TF

Condition Amber: Commander, 51, S2 NCO, ADA 0, engineer (ENG) 0, 53V

Condition Red: S2, S3, FSO

Those positions in blue provide more overhead than actual value added. Green positions are those that have full command of the work place and are able to keep pace. Condition amber is a warning that functions performed by these positions are compromised by both a steady task demand at a high skill level and a propensity to fall behind in the work. Finally, red positions are not able to function at a level that matches the task demands. As new battle information emerges during the scenario, new information is ultimately ignored and critical thinking processes are often paralyzed. The model data indicate that the FSO in particular drops more tasks, enters tasks in queues the most, and has the longest work backlog.

SUMMARY AND CONCLUSIONS

The CoHOST modeling methodology was built and exercised to provide an analysis and decision-making tool for comparing different personnel and equipment design trade-offs for operations in today's and tomorrow's Army. The sample analysis presented before includes 23 personnel performing tasks in a 2-hour MTC scenario. The extensive database that results from the model allows detailed comparisons of task and information flow efficiency and quantitative assessment of soldier workload from several perspectives. Findings from the model show that there are clear differences in how well different staff sections and soldiers within the sections are able to process the incoming information events that trigger their work tasks.

Statistical comparisons of information flow and workload measures between staff sections showed no significant differences, except for the FSO who had an excessive number of

dropped tasks. The S3 battle captain, S2, and S2 NCO also dropped more than 20 of their tasks. Most of the other officers and enlisted soldiers dropped five or fewer tasks; ten soldiers dropped none. This clearly points out the benefit of the NCO in the S2 and S3 sections to assist the officer. The FSO had no NCO for this role for this model run. In other model runs where an NCO assisted the FSO, the FSO's efficiency improved considerably. Other staff sections had no NCO but also had many fewer information events to process. In these sections (S1/S4, ADA, ENG, command group), the officers are used at a productive but not overtaxed level (25% to 50% of their time), and the associated RTOs (radio operators) are not used enough, not at all busy for more than 80% of the scenario.

Workload levels measured by skill demands show very high composite values for all officers as well as the two NCOs. This reflects the high mental demand associated with their tasks; those who can keep pace with their overall task workload have a work pace (use around 50% to 60%) and can do justice to the problem-solving and decision-making nature of these tasks. This is particularly true as reflected by their valuable participation in the staff huddles. The FSO, S2, and S3 have excessively high skill demand levels, are busy in task processes most of the time, and have the worst information flow efficiency. These individuals are the major information processing bottlenecks in the C2 operation.

The cluster analysis, which was performed for all soldiers, combined workload measures to identify groups of soldiers who are severely overtaxed, working at a reasonable pace and load, or are mostly idle and under loaded. From these data and the compelling trends from the separate flow and workload measures, the following conclusions are drawn from this model:

Soldier positions perform their C2 tasks for this MTC scenario at four very different conditions of efficiency:

1. Blue condition - under used and skill demands extremely low.

2. Green condition - good match of skills, work demands, and work pace.

3. Amber condition - able to keep pace with work but with significant queues and constant backlogs.

4. Red condition - over used, cannot keep pace with battle situation information, and high demand for sustained mental processing severely compromises task outcomes and causes bottlenecks in work flow for other staff.

For this sample run, the FSO was in the worst of all task performance conditions with no intermediate level staff NCO to share the high volume of information events and mental processes required.

S2 and S3 NCO positions function much more like the officer cadre than their enlisted cohorts. The NCO may be able to assist in more than just one section in a redesign.

Overall, RTO positions are more idle than busy and are often waiting for input from higher level staff to allow completion of their (the RTO) work.

The high workload demand levels for officer positions are attributable to demand for mental skills in the reasoning (deductive reasoning), speed-loaded (speed of closure, perceptual speed and accuracy), and conceptual (flexibility of closure, selective attention) categories.

The workload demanded of the RTO positions is largely accounted for by oral comprehension, written expression, and fine motor tasks with radio equipment.

RECOMMENDATIONS

The findings from this initial effort of the multi-year research and development project, which was undertaken by ARL in cooperation with USAARMC and the Operational Test and Evaluation Command, have led to the following recommendations:

1. Review and minimize FSO input messages.

2. Add an FS NCO to assist in battle information tracking.

3. Revise RTO message-processing tasks to include more information filtering before "hand-offs," and provide training in applied analysis and critical thinking skills.

4. Use ADA, ENG, S1 staff officers to assist in S3 "look-ahead" tasks and staff huddles to reduce the workload of the FSO and S3.

Figure 11 shows a chart that summarizes the problem areas and provides a decision tree to work through several options for alleviating the inefficiencies and overloads resulting from the digitized TOC.

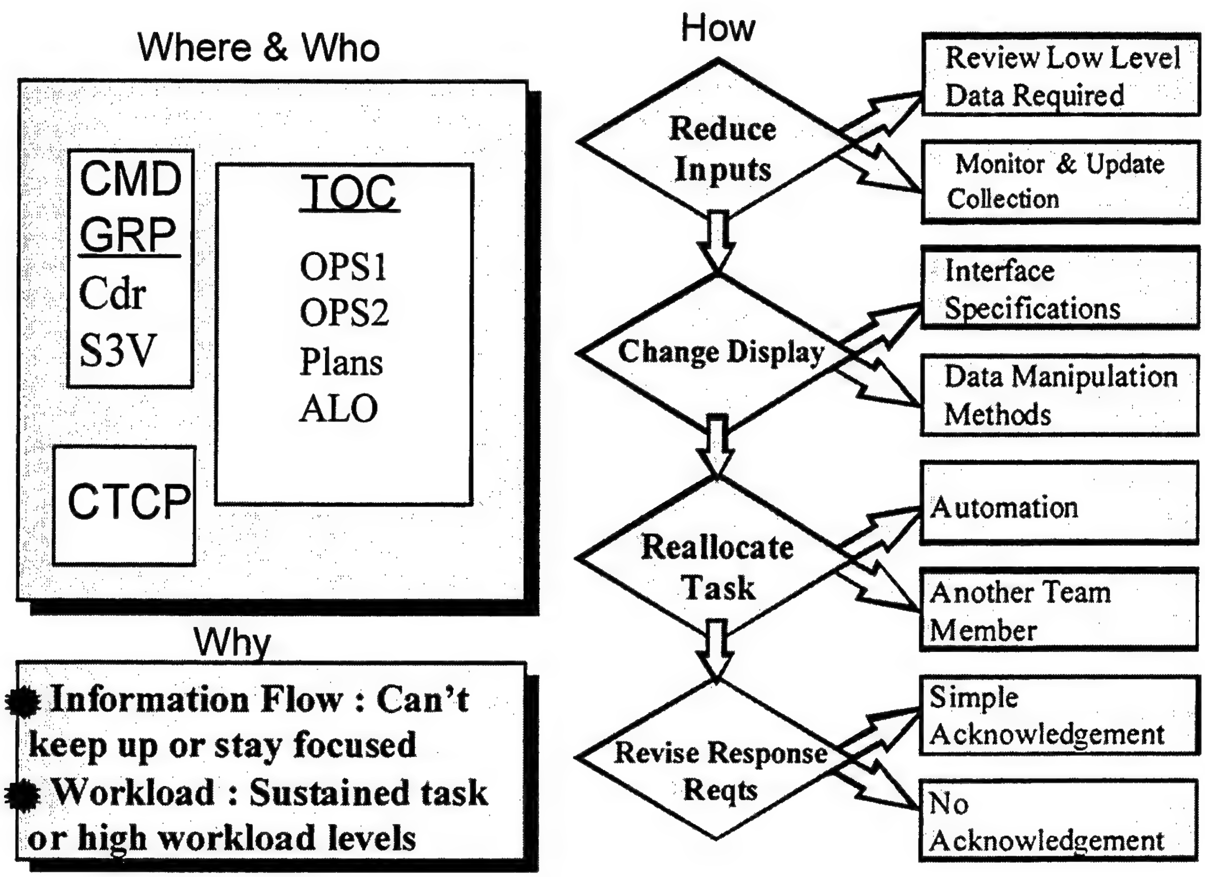


Figure 11. Options to resolve overloads and flow bottlenecks.

Option 1, reduce information input, suggests that those data coming to the S3 and intelligence positions on MCS/P and ASAS should be screened in advance, and voice radio monitoring requirements for these positions should be eliminated to allow full focus on the digital data and communications links.

> Decrease information message traffic to S3 and intelligence positions
> Make staff huddles all digital so that the workstation does not have to be unattended for face-to-face work.

Option 2, change displays, suggests that interface redesign and information access should be a strong software design focus. The large screen display was provided for C2Vs in the TOCs but not used.

> Provide advanced visualization and intelligent agent interface technologies to all positions to determine best fit of technology to work requirements.

Redesign task networks, including proactive large screen display use.

Option 3, reallocate information, suggests reducing the tasks from an overloaded position to another individual or to an automated processor.

Assign certain tasks to be shared between more than one position, so that overload is anticipated and mitigated.

Increase duties of liaison officer and FS positions in battle tracking.

Option 4, redefine response requirements, ensures that all incoming information is prioritized and partitions according to when and if it must be attended and provides automatic acknowledgments when needed.

Eliminate large message queues in which each new message must be acknowledged.

Assign the battle captain to rotate into plans section for selected time intervals.

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13. ABSTRACT *(Maximum 200 words)*

A multi-year effort was conducted to investigate the impact on human cognitive and physical performance capabilities resulting from the introduction of a new Army command and control vehicle with modernized digital communications systems. This was a joint effort by the U.S. Army Research Laboratory in partnership with the Directorate of Force Developments at the U.S. Armor Center and School at Fort Knox, Kentucky, and the U.S. Army Operational Test and Evaluation Command at Alexandria, Virginia. Literature searches and background investigations were conducted, and a model architecture based on a taxonomy of human performance was developed. A computer simulation design and methodology was implemented with these taxonomic-based descriptors of human performance in the military command and control domain, using a commercially available simulation programming language. A series of computer models was written and results were developed that suggest that automation alone does not necessarily improve human performance.

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